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Investigation on flexural strength during fiber laser cutting of alumina

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Abstract

This article presents the optimization of the flexural strength of alumina with the thickness of 0.63 mm during single mode fiber laser cutting for electrical applications. The results of the optimization by design of experiments reveals that the position of the focus has the highest influence on the strength. The maximum strength during cw fusion cutting is measured to 395 MPa at 300 mm/s compared to 520 MPa by scribe and break. To cut small complex contours a digital modulation is used resulting in a strength of 506 MPa at 1 mm/s in combination with a Weibull modulus of 29.

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Keywords: laser fusion cutting, alumina, flecural strengh;

1. Motivation / State of the Art

In the last years there is an increasing demand in alumina ceramics for substrates in the electronic industry due to many advantages over paper and glass fiber reinforced plastics.Electronics on alumina substrates are found in automotive, sensor systems, telecommunication and power electronics. Compared to standard FR4 substrates alumina has a much higher hardness, thermal conductivity, maximum operation temperature and wear resistance [1].

Due to itshardness and brittleness the only mechanical method processing alumina is diamond abrasive cutting [2]. Because even diamond grindings tends to result in low processing speeds and high tool wear,different laser processing strategies are commonly in use.In order to reach high velocities during separating straight lines, mostlyCO_2lasers are employed for either fusion cutting or a scribe and break method [3, 4]. Another approach is described by Tsai *et. al.*[5] using a focused Nd:YAG laser for grooving and a defocused CO_2 laser to induce mechanical stress to fracture the ceramic. Yet, this method has mayor

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disadvantages cutting corners because the crack doesn´t follow the scribed path. In order to cut viasoften fusion cutting is used which lead to thermal induced stress and cracks at the processed surface which can reduce the stability of the ceramic [4, 6].In this contribution, we measure the influence of laser cutting with a single mode fiber laser on the flexural strength of alumina and maximize the flexuralstrength by parameter optimization.

2. Experimental

In this study, a continuous wave 500 W single mode fiber laser (IPG Photonics) was used to perform the experiments. The laser system is equipped with linear stages (x,y) for the workpiece (Aerotech) and a fine cutting head (Precitec) attached to a linear drive (z). The assisted gas nitrogen with purity greater than 99.999 % flows coaxial to the laser beam. The gas nozzle has a diameter between 0.8 mm and 0.3 mm and its distance to the workpiece is positioned by thez-linear drive. The emission wavelength of the laser is specified to be 1070 nm in conjunction with a beam propagation factor of $M^2 < 1.1$. The raw beam diameter of 7.25 mm is focused by a lens with focal length of 50 mm. The resulting Rayleigh length is calculated to 70 µm. The Laser system is equipped with a position synchronous output (PSO) to modulate the laser digitally. Using the PSO the laser is switched on for an adjustable time after the drives moved a given distance.

The alumina substrates (CeramTec)withthickness of 0.63 mm are the most common ceramic material in electronic industry. The flexural strength of this alumina is specified with 390 MPain combination with a Weibullmodolus of 10. In order to run bending tests in the experiments the ceramic gets cut into 24 mm long and 3 mm wide samples.

To measure the flexural strength,a 3-point bendingtest machine (Thuemler)is used with 20 mm distance between the twocontact points.The flexural strength σ is calculated with formula 1 from the maximum force F which the sample withstands [1]. Here l is the distance between the two contact points, b stands for the width of the sample and d expresses the sample thickness.

$$\sigma = \frac{3 \cdot F \cdot l}{2 \cdot b \cdot d^2} \tag{1}$$

3. Results and Discussion

For comparison and inorder to obtain a better quantification of the measured strength four samples of alumina were produced by scribe and break achieving a mean flexural strength of 520 MPa.

To evaluate the influence of different machine parameters an experimental design with 4 parameters and 16 experimentsat constant laser power of 500 W is run. The flexural strength is measured and the influence of the laser parameters shown in table 1 are calculated with acommercialsoftware. The position of the focus has the most important influence on the strength, where a higher strength is achieved at lower focus positions (a negative value expresses a focus position below the surface of the workpiece). Opposite to this, the velocity has almost no influence in the analyzed interval.The maximum measured strength of 395 MPa(velocity 300 mm/s, gas pressure 6 bar, position of focus 0.5 mm below workpiece surface, nozzle diameter 0.8 mm) is about the value provided from the datasheet while some parameter combinations which results in a breakup during cutting are valuated with 0 MPa. Figure 1 (a) shows the cutting edge of alumina with a parameter combination similar to that leading to the highest flexural strength, however with a lower cutting velocityand a smaller nozzle diameter. In this regime the crack network can be clearly seen while the striations of the glassy phase that covers the ceramic with a thickness of a few microns are perpendicular to the cracks. Based on thermal simulations Yilbas*et. al.* [4] found that cracks are caused by the resolidification of the glassy phase which complements with the cracks being perpendicular to the striations. The width of the cracks is measured to about 1 micron.

Table 1.Influences of different laser parameters on the flexural strength during cw cutting of straight lines

Parameter	Parameter space	Influence on flexural strength
Position of focus	-0.5 mm to -0.1 mm	-63 MPa
Velocity	50 mm/s to 300 mm/s	-0.5 MPa
Nozzle diameter	0.3 mm to 0.8 mm	-29 MPa
Gas pressure	6 bar to 12 bar	-23 MPa

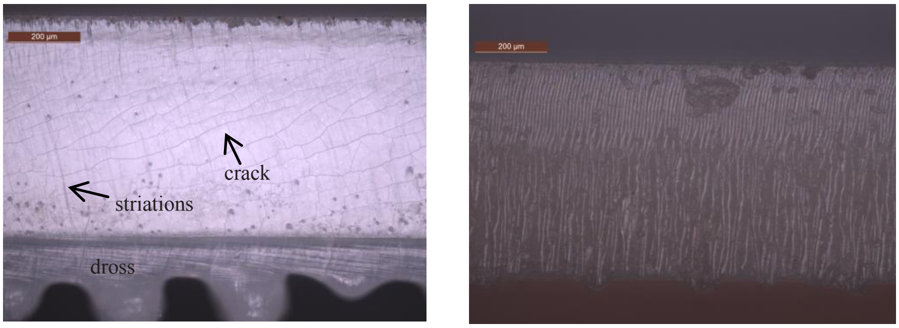

Fig. 1.Optical micrograph (measured with Leica DM 6000) showing the cutting edge of alumina substrate with fiber laser at 500 W with (a) 100 mm/s without modulation ; (b) 1 mm/s with PSO using 10 µm pulse distance and 1 ms pulse time.

In order to cut small contours, the parameter combination described above leads to a mechanical break of the ceramic. To avoid this, the laser is digitallymodulated.Using a velocity of 1mm/s and a switch on time of 1 ms after the drives travel 10 µm even small and complex contours are cut without breakup (other parameters: position of focus -0.5 mm, gas pressure 6 bar, nozzle diameter 0.3 mm).Figure 1 (b) showsthe cutting edge of a digitally modulated cut at which the striation at the upper third have a width of about 10 µm which equates the pulse distance. Examining the flexural strength using digital modulation a mean value of 506 MPa is achieved which is almost as high as the scribe and break value. The Weibull modulus is calculated to 29 with a 95 % confidence interval between 16 and 46. However, at higher velocities of 3 mm/s the strength is reduced by about 20 %

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